

A Possible Planetary Event OGLE-2002-BLG-055

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ABSTRACT

The microlensing event OGLE-2002-BLG-055 has a single, but very reliable data point, deviating upward from a single source microlensing light curve by 0.6 mag. The simplest interpretation calls for a binary lens with a strong parallax effect and the mass ratio in the range 0.01 - 0.001, putting the companion in the Jupiter mass range. Given only a single deviant point it is impossible to fit a unique model. We propose a modification of OGLE observing strategy: instant verification of a reality of future deviant points, followed by a frequent time sampling, to make a unique model fit possible.

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1 Introduction

Mao and Paczyński (1991) and Gould and Loeb (1992) proposed a search for planets using gravitational microlensing. The results so far have been inconclusive (e.g. Bennett et al. 1999, Rhie et al. 2000, Albrow et al. 2000, Gaudi et al. 2002). One of us (Jaroszyński 2002) analyzed 18 candidate binary microlensing events from the catalog of OGLE-II microlensing events (Woźniak et al. 2001). In two cases: SC20_1793 and SC20_3525 well fitting models with extreme mass ratios were found, indicating a possibility of planetary events. Unfortunately, neither case was very strong, as alternative models were also possible.

In 2001 OGLE-III (Udalski et al. 2002) begun its operation, and almost 400 candidate events were detected toward the Galactic Bulge in the 2002 observing season:

<http://www.astrouw.edu.pl/~ogle/ogle3/ews/ews.html>

Among them a number of events showed isolated measurements deviating a lot from otherwise smooth light curves. While some of them were due to various instrumental (or cosmic ray) effects, some might be real. In particular, the event OGLE-2002-BLG-055, as shown in Fig. 1, had a single data point which was 0.6 mag ‘too bright’. The reality of this measurements was verified on the CCD image by Dr. A. Udalski (private communication). The fact that nearby points do not

deviate appreciably suggests that this may be a binary event with an extreme mass ratio, i.e. it may be an evidence for a planet.

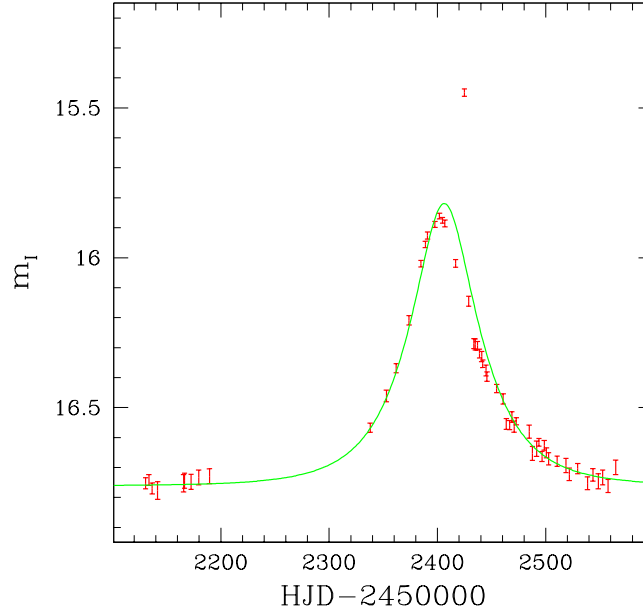


Figure 1: The event 2002-BLG-055 as presented in the OGLE website with the model light curve.

2 Models of the event

After removing the deviating point from the data we attempt to fit the observations with a *standard* single lens model taking into account the possible blending of the source light with the light from the lens and/or close neighbors. Since the event has a long time scale, we also employ a *parallax* model taking into account effects of the Earth orbital motion and an *acceleration* model (compare Smith, Mao, and Paczyński 2002) taking into account changes in the relative lens - source velocity of unspecified origin. The results are shown in Fig.2.

For comparison we repeat the fits after removing the points adjacent to the deviating one - a total of three, five or seven of them. For each data set we find that the parallax and acceleration models give fits of similar quality, while the standard model is significantly worse. Several single lens models are compared in Table.1.

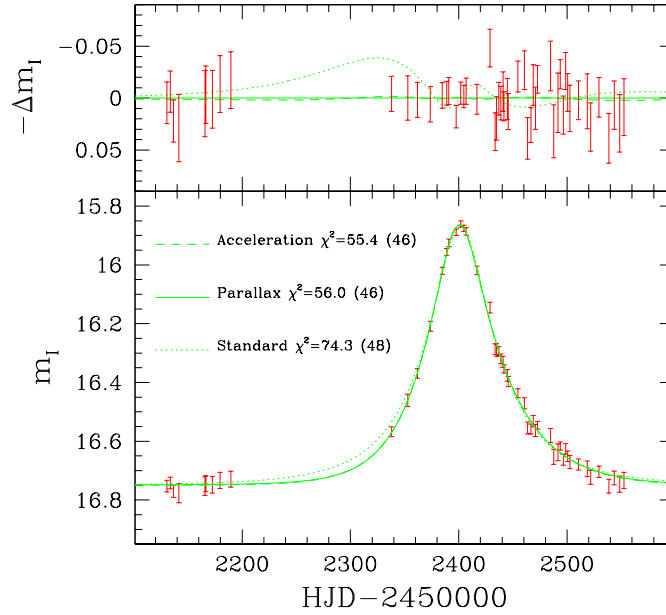


Figure 2: Single lens model fits to the data with the single deviant point removed. The plots for standard (dotted), parallax (solid) and acceleration (dashed) models are shown against the data (error bars) in the lower panel. In the upper panel we show the differences relative to the parallax model. The solid and dashed lines are almost indistinguishable on the scale of this figure.

The EWS light curves and their error estimates should be treated as preliminary. The proper calibration of the measurement errors will be possible in the future, when photometric reduction is repeated with good templates. The observations of 2001 season lasted too short, to properly estimate the possible intrinsic scatter in the source luminosity. The future seasons will provide such information. Our experiments with different data sets show that χ^2 per one degree of freedom (DOF) stops to decrease after removing 3 – 5 observations from the vicinity of the deviating point. We arbitrarily assume that $\chi^2/DOF = 1$ for the parallax model fitted to the data set with five points removed. This is equivalent to multiplying all estimated photometric errors by a factor of 1.685. All the results reported above use the rescaled errors and χ^2 values. The acceleration models give formally better fits to the data as compared to the parallax models but the difference is not large enough to give them high preference.

Next we look for the binary lens model of the event. The binary lens has two

T a b l e 1
Single lens fits

N	Standard	Parallax	Acceleration
1	72.6 (48)	54.7 (46)	54.1 (46)
3	64.6 (46)	45.6 (44)	44.4 (44)
5	60.5 (44)	42.0 (42)	40.9 (42)
7	58.1 (42)	40.7 (40)	39.7 (40)

A comparison of fits to different data sets. The first column gives the number of points removed from the original data. The rescaled values of χ^2 are given in columns 2 – 4 for three kinds of models, showing also DOF numbers in parentheses.

parameters: q - the mass ratio ($q \leq 1$ by convention), and d - component separation expressed in Einstein radius (r_E) units. The event is also characterized by the impact parameter u_0 relative to the center of mass, the angle β giving the source direction of motion, the time of the source passage by the center of mass t_0 , the Einstein time t_E , the basic stellar magnitude I_0 of the source and the blend, and the blending parameter f ($f \leq 1$), which shows what part of the basic flux is emitted by the source itself. The parallax effect introduces another two parameters, the ratio of the Einstein radius projected into the observer's plane to the Earth orbit semi major axis and the angle giving the direction of the source motion relative to the Earth orbit orientation. Similarly the acceleration models are described by another two parameters giving the two components of the source acceleration. As one can see even a point source seen through a binary lens requires 8 – 10 parameters to fully describe the model.

Following Jaroszyński (2002) we first made a low resolution scan of the parameter space, specifically looking for the best fits at fixed values of (q, d) , and covering a broad range $0.001 \leq q \leq 1$, $0.1 \leq d \leq 10$. The models with $d \approx 1$ and q close to 0.001 or 0.01 are clearly preferred. Using many starting points in the vicinity of the χ^2 minima found in the scans we refined our search allowing for continuous changes in all parameters. The conclusion does not change: in every kind of model (standard / parallax / acceleration) there seem to be two local minima of χ^2 representing fits of statistically similar quality. The light curves related to the two minima are different. For lower q value the source is crossing a caustic

while for the larger value of q the light curve represents a caustic cusp approach. We show the relevant parts of model light curves for the parallax model in Fig.3. The χ^2 values for the three kinds of binary lens models are given with the corre-

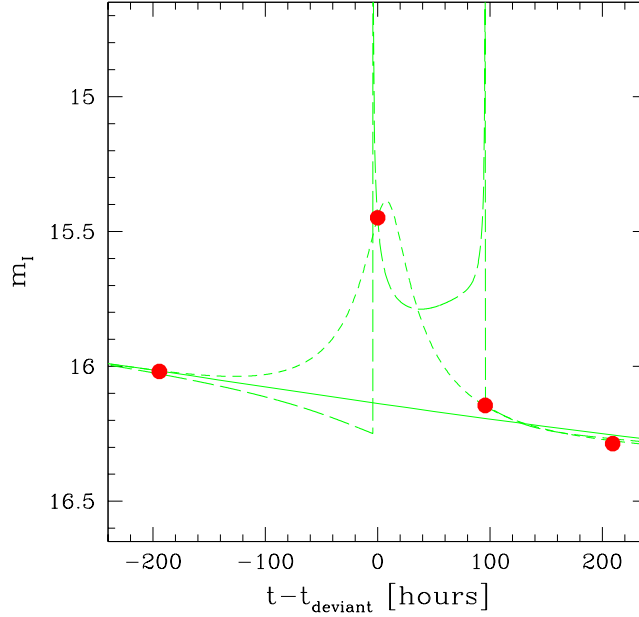


Figure 3: The model light curves near the "deviating" point. The curves correspond to the binary lens models with parallax for the mass ratios $q = 0.0097$ (short dashed line) and $q = 0.0015$ (long dashed line). The single lens model with parallax fitted to data with one point removed is shown for comparison as solid line.

sponding q - values in Table.2. The parallax and acceleration models do not differ significantly but are much better than the standard model. We also note that the binary model fits to the full data set are of the same quality as corresponding single lens models with three data points removed, which have the same number of the degrees of freedom.

The results presented above are based on calculations performed for a point source. We have also made less extensive calculations using an extended source and the approach described by Mao and Loeb (2001). While the detailed shapes of light curves change, the concurrent models with $q \approx 10^{-3}$ and $q \approx 10^{-2}$ are still present. In another numerical experiment we add few artificial data points resulting from one of the models into the crucial part of the light curve. This proves to be sufficient to break the degeneracy of the solutions.

T a b l e 2
Binary lens fits

Standard (46)		Parallax (44)		Acceleration (44)	
q	χ^2	q	χ^2	q	χ^2
0.0487	55.4	0.0097	42.6	0.0131	42.2
0.0023	59.1	0.0015	43.4	0.0015	43.3

The values of mass ratio q and corresponding χ^2 values for three kinds of models. Each entry corresponds to a local χ^2 minimum. The DOF numbers are given in parentheses.

Both single lens models ignoring one data point and binary lens models based on the whole data set give consistent estimates of the non uniformity in the relative source - lens motion. Assuming the effect is due to the parallax, we get an estimate of the Einstein radius depending on the lens position. Its value changes linearly from $r_E \approx 2.5$ AU very close to the observer to 0 near the source. Since the Einstein radius depends on the lens mass and its position within the Galaxy, a typical parameters of the system can be imagined: lens of $\approx 0.3 M_\odot$ at ≈ 2 kpc from Earth. The time scales given by our models, $t_E \approx 55^d$ require the lens - source relative velocity $\approx 60 \text{ km s}^{-1}$, which is consistent with the effect caused by the Galactic disk differential rotation for a lens at 2 kpc. The position of the lens much closer to the observer would require unnaturally high relative velocity, and for a far away lens - much too slow relative motion. The source radius $\approx 10^1 R_\odot$ is ≈ 150 times smaller than the Einstein radius projected into the lens plane, so the caustic crossing (if present) takes few hours.

3 Discussion

Given only one strongly deviating data point it is not possible to determine a unique mass ratio for a binary lens model. It may also be difficult to persuade skeptics that a single point should be treated as a proof that the lens is binary. Therefore, rather than argue about OGLE-2002-BLG-055 we propose a modest modification of the OGLE Early Warning System (EWS, Udalski et al. 1994). The current system alerts on a time scale of several days, as it is tuned to stellar lenses, and it currently monitors light variations of about 150 million stars on a roughly 24 hour cycle. At any given time there are only several hundred recognized microlensing event,

which is less than 1/100,000 of all stars. It should be relatively easy to intercept the data related to these objects and to process them within minutes of the CCD exposure and to present them to the observer in a form of a standard EWS light curve, as shown on the WWW. In principle a data point deviating from the model fitted to the lensing event could be identified with software, but there is no urgent need for that: we have identified only 27 strongly deviant points among nearly 400 light curves of microlensing events detected in 2002, i.e. one per week. All these points were less extreme than the one in OGLE-2002-BLG-055, and very likely most of them are not real anomalies. Upon detecting a possible anomaly the observer may interrupt the prescheduled observing procedure and take a second exposure of the interesting field. If the anomaly is confirmed - the observing schedule could be interrupted to provide frequent measurements of the interesting event. Figure 3 in this paper and our simulations indicate that extra observations should be sufficient to distinguish between models with various mass ratio. Our estimate of the possible caustic crossing time for the event OGLE-2002-BLG-055 suggests that it would be enough to make observations once per hour.

Note, that given proper sampling of a planetary event should provide a fairly easy determination of the mass ratio. A fit to the stellar event provides the time scale t_E , and the impact parameter u_0 . The timing of a short duration anomaly provides information about an approximate location of the planet in the lens plane, and the mass ratio is the only parameter that has to be thoroughly searched for.

The event OGLE-2002-BLG-055 exhibited a strong parallax effect. Had the rapid EWS system been in place there is a good chance that a caustic crossing due to planetary lensing would have been detected, and the source would have been resolved, i.e. the relative proper motion would have been determined. Combining all three elements: the stellar event time scale t_E , the parallax effect, and the relative proper motion, would allow not only to determine the mass ratio of the system, but also the masses.

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